SUBJECT: CSM Consumables Limits of an Extended Duration Flight - Case 320

DATE: May 5, 1969

FROM: S. S. Fineblum

MEMORANDUM FOR FILE

INTRODUCTION

The maximum endurance of both the nominal Apollo and extended missions are limited by the loading of CSM hydrogen, oxygen, and water; the electrical load; other thermal loads; and the effectiveness of the ECS radiators. This memo reports an updated FORTRAN recomputation of an earlier study of the limits of CSM extended duration.[1]

It is not intended that these highly simplified computations duplicate the output of the sophisticated and detailed computer program developed at MSC.[2,3] However, these results will be useful in establishing the approximate quick-look mission consequences of decisions on consumables loading, water management, and power level.

Among the more important consumable considerations which limit CSM missions are hydrogen as a reactant in the fuel cells and water as an expendable refrigerant. The hydrogen consumption is a simple function of the electrical current of the fuel cells, while the water consumption is primarily determined by the requirement of evaporators to rid the spacecraft of excess internal heat. The program computes both the hydrogen and water consumption and the mission limits for a wide range of average fuel cell power levels and radiator effectiveness.

THE PROGRAM

The computer program, which is presented in the appendix along with a sample print-out, starts with the current as the

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[1]Fineblum, S. S., "Consumables Operational Limits of an Extended Duration Flight on Mission AS-204 - Case 320" Memorandum for File, January 27, 1969.

[2]Stokes, R. E., "The MSC CSM Electrical Power Subsystem Program," MSC Internal Note No. 67-FM-200, December 27, 1967.

[3]Chahine, N. T., et. al., "Apollo CSM ECS/Thermal Analysis Program", 05952-H358Ro-00 TRW Note 68-FMT-592, January, 1968

basic system variable. Using the data of the fuel cell charac-
teristics in the memory, the program prints out the gross fuel
cell water production and hydrogen consumption as well as vol-
tage. The net watts into the Command Module is computed by
subtracting the power used to operate the fuel cells themselves
from the total fuel cell power. The total heat load, which
consists of metabolic and solar heat in addition to the heat
generated by the CM electrical components, is compared to the
parameter of radiator effectiveness. Whenever the net radiator
thermal emission is less than the total heat load the evapora-
tor requirement for water is computed. This water flow is
subtracted from net water production and the loss in water re-
serves is used to compute water-limited endurance.

The program is flexible in that the constants as
well as the radiator effectiveness could be determined by sub-
routines which may be added later. Thus, these computations
may be easily extended to show the effect of more variables or
modified for new or extended missions. In addition this program,
with some modification and with the electrical power schedule
as an additional input, could compute the reserves at each
phase of the mission.

RESULTS FOR NOMINAL MISSION

With the assumptions stated (note top of sample print-
out) the results indicate that the nominal mission is safely
within the hydrogen and water supply (reduced to 80% of capacity)
with a mission average electrical load of 1500 watts and a
slightly degraded ($\alpha = .30$) radiator. The variation of hydrogen
and water consumption and endurance as a function of electrical
power and radiator effectiveness are plotted in Figures 1-3.

2033-SSF-scs   S. S. Fineblum
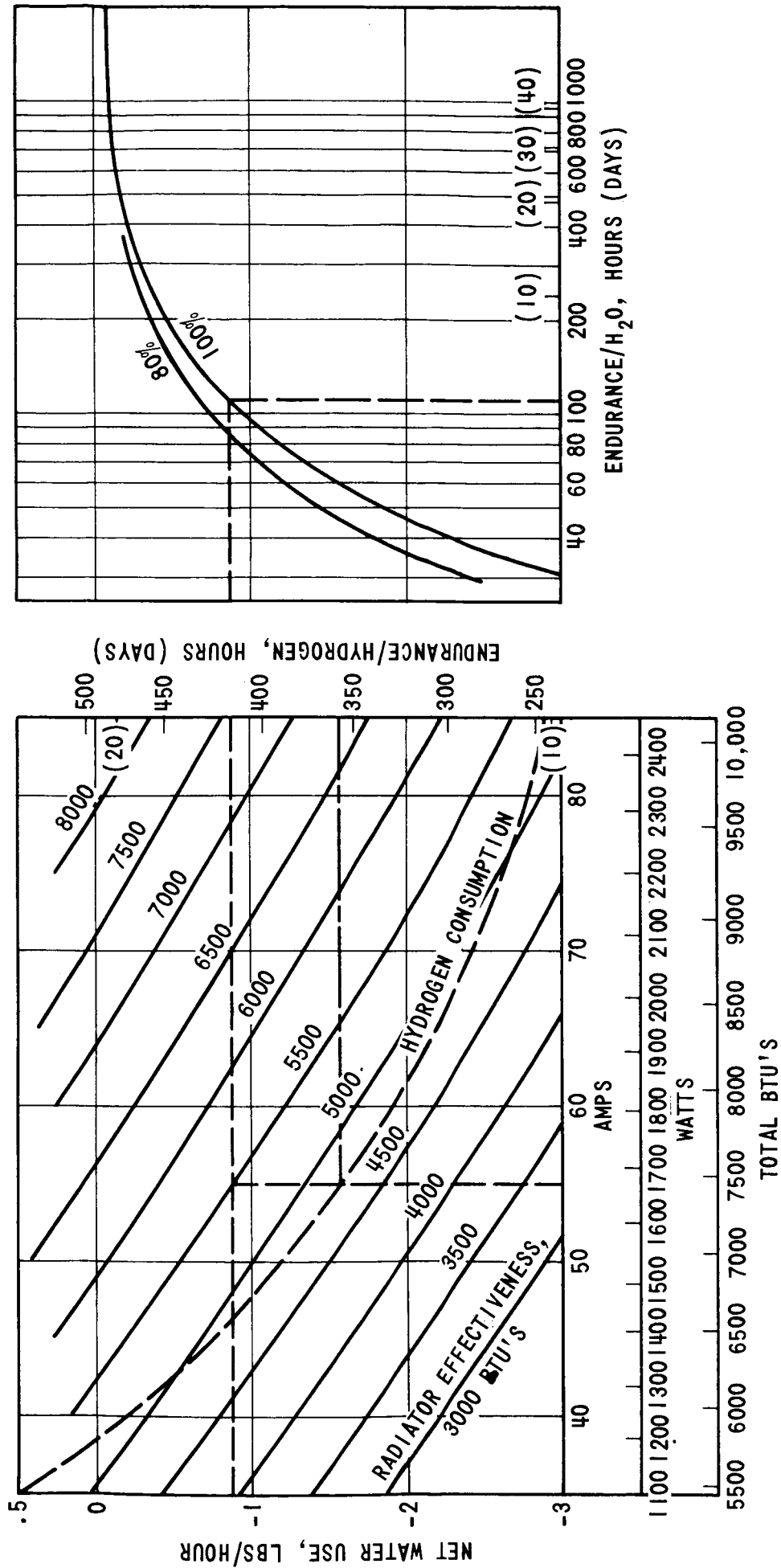
Attachments
  Figures 1-3.
  Appendix

FIGURE 1 - CSM LIMITS—THREE FUEL CELLS.
ALL CURVES SHOW AVERAGE CONSUMPTION
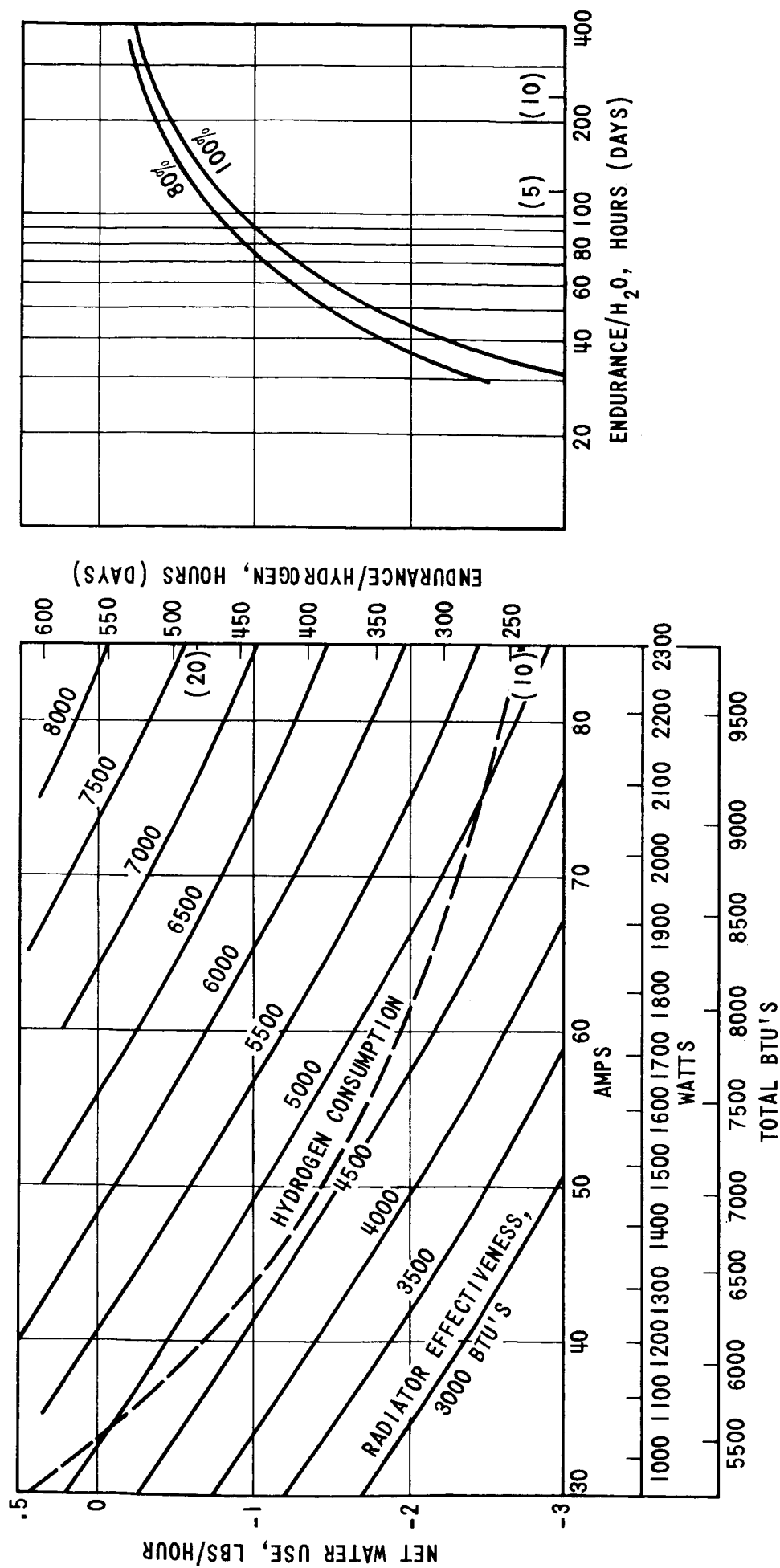
FIGURE 11 — CSM LIMITS—TWO FUEL CELLS.
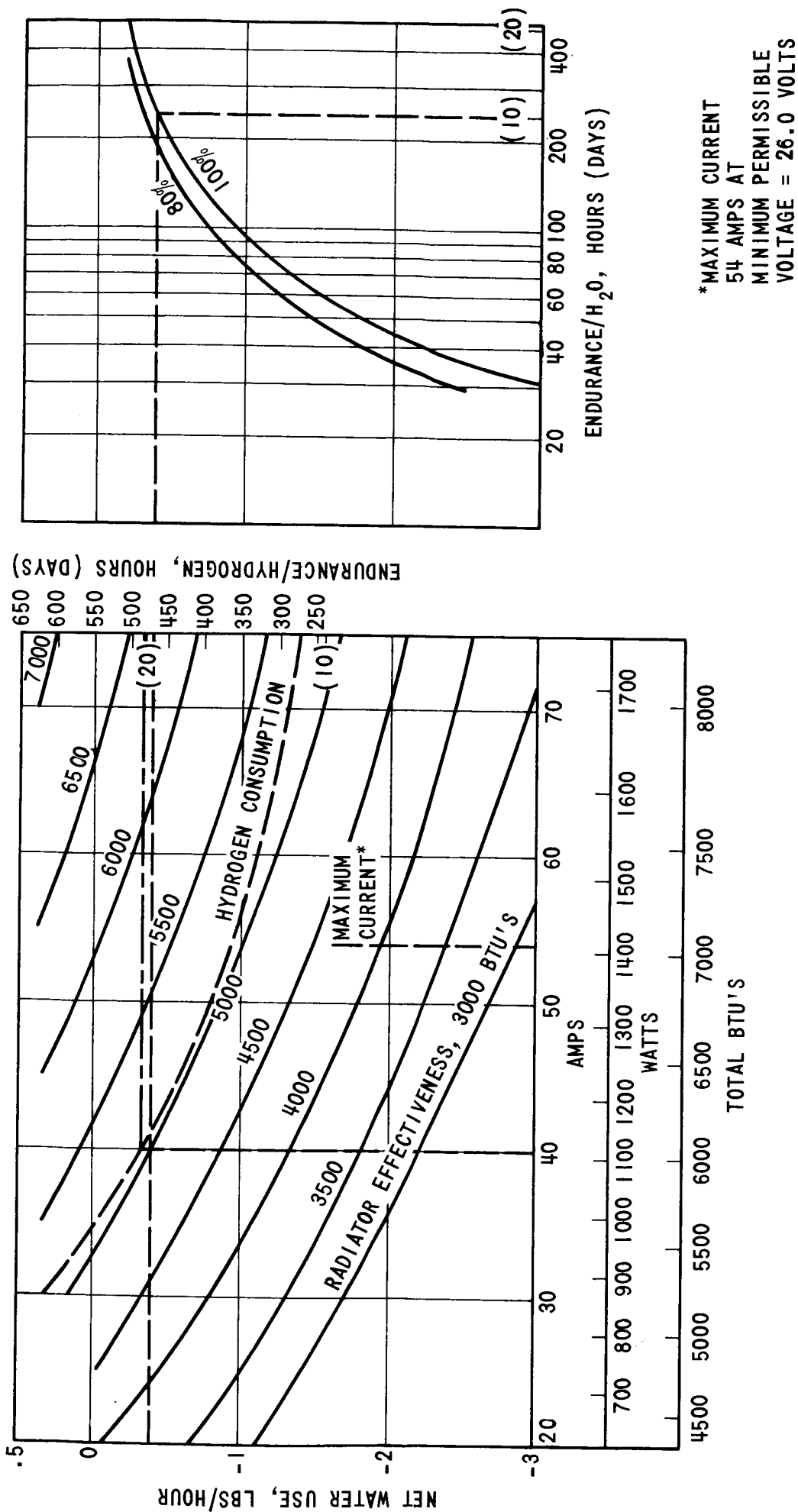ALL CURVES SHOW AVERAGE CONSUMPTION

FIGURE III — CSM LIMITS—ONE FUEL CELL
ALL CURVES SHOW AVERAGE CONSUMPTION

*MAXIMUM CURRENT
54 AMPS AT
MINIMUM PERMISSIBLE
VOLTAGE = 26.0 VOLTS

APPENDIX

DEFINITIONS OF MNEMONICS
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 1         AMPS = FUEL CELL CURRENT IN AMPS
 2         VOLTS = FUEL CELL TERMINAL VOLTAGE IN VOLTS
 3         WATTS = VOLTS TIMES AMPS,ELECTRICAL POWER IN WATTS
 4         SWATTS = STANDARD WATTS IN WATTS
 5         FCUTLS = POWER CONSUMED IN OPERATION OF FUEL CELL IN WATTS
 6         EBTU = HEAT EQUIVALENT OF ELECTRICAL POWER IN BTU/HR
 7         EX TBTU = HEAT LOST OR GAINED THROUGH STRUCTURE IN BTU/HR
 8         MBTU = METABOLIC HEAT LOAD IN BTU/HR
 9         QLIOH = LIOH HEAT OF ABSORBTION IN BTU/HR
10         RADBTU = NET ENERGY REJECTED TO SPACE BY EMISSION IN BTU/HR
11         TOBTU = TOTAL NET THERMAL LOAD IN BTU/HR
12         SFCWP = SPECIFIC FUEL CELL WATER PRODUCTION IN LB/HR/AMP
13         GFCWP = GROSS FUEL CELL WATER PRODUCTION RATE IN LBH2O/HR


14         WALOS = METABOLIC LOSS IN LB H2//HR OF WATER
15         NFCWP = NET WATER PRODUCTION IN LB H2O/HR
16         DEBTU = THERMAL DEFICIENCY AFTER RADIATION IN BTU/HR
17         BTULA = LATENT HEAT OF EVAPORATION OF WATER IN BTU/LB
18         BOILER = WATER BOILER CONSUMPTION IN LB/HR
19         DEWAT = WATER STORAGE CHANGE IN LB/HR
20         TWATR = TOTAL WATER STORAGE IN LB
21         ENDWA = WATER LIMITED ENDURANCE IN HOURS
22         ELCH2 = ELECTROCHEMICAL COEFFICIENT OF COMBINATION IN LB/HR/AMP
23         ECH2U = POUNDS OF USAGE IN H2/HR
24         PRH2U = PURGE H2 USE IN LB/HR
25         TOH2U = TOTAL H2 USE IN LB/HR
26         TOH2ST = TOTAL H2 STORAGE IN LBS
27         ENDH2 = H2 LIMITED ENDURANCE IN HRS
28         BWATTS = WATTS TO NON FUEL CELL BUSSES IN WATTS
29         SMWATT = WATTS CONSUMED IN THE SERVICE MODULE IN WATTS
30         TOSMWTS = TOTAL POWER CONSUMED IN THE SM(INCLUDING FCUTLS)
31 NOTE NFCOL = NUMBER OF FUEL CELLS ON LINE (INTEGER 1, 2 OR 3)
           IF THERE ARE THREE FUEL CELLS ON LINE THE UTILITY POWER
           KNOWN AS FCUTLS WILL BE 240 WATTS, FOR 2 FUEL CELLS,
           FCUTLS = 160 WATTS, WITH ONE FUEL CELL 80 WATTS. THESE
           MAY CHANGE. IN ADDITION THE VOLT-AMP RELATIONSHIP VARIES
           WITH THE NUMBER OF FUEL CELLS ON LINE.
32 NOTE DATA IS FROM MISSION MODULAR DATA BLOK SID 66-1245 JAN 67
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C       EXECUTABLE STATEMENTS
C
        READ(5,INPUT)
C
        DO 10 I=1,15
   10   RADBTU(I+1)=RADBTU(I)+500
C
        DO 60 I=1,N
        WATTS(I)=AMPS(I)*VOLTS(I)
        BWATTS(I)=WATTS(I)-FCUTLS
        EBTU(I)=BWATTS(I)*3.413
        TOBTU(I)=EBTU(I)+EXTBTU+BTUMET+QLIOH
C
        GFCWP(I)=AMPS(I)*SFCWP
        NFCWP(I)=GFCWP(I)-WALOS
C
        DO 20 J=1,15
        DEBTU(I,J)=TOBTU(I)-RADBTU(J)
        IF(DEBTU(I,J))20,20,


        BOILER(I,J)=DEBTU(I,J)/BTULA
        DEWAT(I,J)=NFCWP(I)-BOILER(I,J)
C
        GFCWP(I)=AMPS(I)*SFCWP
        NFCWP(I)=GFCWP(I)-WALOS
        ECH2U(I)=AMPS(I)*ELCH2
        TOH2U(I)=ECH2U(I)+PRH2U
        ENDH2(I)=TOH2ST/TOH2U(I)
        IF(DEWAT(I,J))    ,20,20
        ENDWA(I,J)=TWATR/DEWAT(I,J)
   20   CONTINUE
C
   60   CONTINUE
C
```

EPS AND THERMAL CONSUMABLES

NFCOL=3
AALOS= .330 SFCHP= .235-01 QLIOH= 360.0 EXTBTU= 475.0 THATH= 92.0 BTULA= 1060.0
SWATT= .0 ATUMET= 1500.0 ELCH2= .2611-02 PRH2U= .015 TOSMAT= 240.0 TOH2ST= 57.0

FCUTLS= 240.0

AMPS	VOLTS	WATTS	TOH2U	ENDH2	TOBTU	SFCPP	KADBTU	DEBTU	BOILER	DEMAT	ENDWA
35	31.46	1101.10	.106	535.79	5473.9	.49	2500.0	2973.9	2.81	-2.31	39.77
							3000.0	2473.9	2.33	-1.84	49.96
							3500.0	1973.9	1.86	-1.37	67.17
							4000.0	1473.9	1.39	-.90	102.45
							4500.0	973.9	.92	-.43	215.81
							5000.0	473.9	.45	.05	
40	31.21	1248.40	.119	477.23	5976.7	.61	2500.0	3476.7	3.28	-2.67	34.46
							3000.0	2976.7	2.81	-2.20	41.85
							3500.0	2476.7	2.34	-1.73	53.29
							4000.0	1976.7	1.86	-1.25	73.32
							4500.0	1476.7	1.39	-.78	117.48
							5000.0	976.7	.92	-.31	295.45
							5500.0	476.7	.45	.16	
45	30.96	1393.20	.132	430.20	6470.9	.73	2500.0	3970.9	3.75	-3.02	30.48
							3000.0	3470.9	3.27	-2.55	36.12
							3500.0	2970.9	2.80	-2.08	44.33
							4000.0	2470.9	2.33	-1.60	57.37
							4500.0	1970.9	1.86	-1.13	81.29
							5000.0	1470.9	1.39	-.66	139.37
							5500.0	970.9	.92	-.19	488.28
							6000.0	470.9	.44	.28	
50	30.71	1535.50	.146	391.62	6956.5	.84	2500.0	4456.5	4.20	-3.36	27.39
							3000.0	3956.5	3.73	-2.89	31.86
							3500.0	3456.5	3.26	-2.42	38.08
							4000.0	2956.5	2.79	-1.94	47.32
							4500.0	2456.5	2.32	-1.47	62.48
							5000.0	1956.5	1.85	-1.00	91.93
							5500.0	1456.5	1.37	-.53	173.88
							6000.0	956.5	.90	-.06	1602.86
							6500.0	456.5	.43	.41	
55	30.46	1675.30	.159	359.39	7433.7	.96	2500.0	4933.7	4.65	-3.69	24.92
							3000.0	4433.7	4.18	-3.22	28.57
							3500.0	3933.7	3.71	-2.75	33.47
							4000.0	3433.7	3.24	-2.28	40.41
							4500.0	2933.7	2.77	-1.81	50.97
							5000.0	2433.7	2.30	-1.33	69.00
							5500.0	1933.7	1.82	-.86	106.76
							6000.0	1433.7	1.35	-.39	235.88
							6500.0	933.7	.88	.08	
							7000.0	433.7	.41	.55	
60	30.21	1812.60	.172	332.05	7902.3	1.06	2500.0	5402.3	5.10	-4.02	22.91
							3000.0	4902.3	4.62	-3.54	25.95
							3500.0	4402.3	4.15	-3.07	29.94
							4000.0	3902.3	3.68	-2.60	35.37
							4500.0	3402.3	3.21	-2.13	43.20
							5000.0	2902.3	2.74	-1.66	55.49
							5500.0	2402.3	2.27	-1.19	77.55